Frankford Arsenal
Philadelphia 37, Penna.

Memorandum Report M63-1-2
January 1963
OMS 5522.11.441
DA Project 513-01-008

DETERMINATION OF THE MECHANISMS GOVERNING THE INFLOW OF MOISTURE PAST A ROTARY SEAL

STATUS REPORT

Prepared by: Bernard Hoffman
BERNARD HOFFMAN
Mechanical Engineer

Reviewed by: E. Roffman
E. ROFFMAN
Chief, Engineering Laboratory Branch

Charles J. Dobson
CHARLES J. DOBSON
Systems Engineer

Approved by: Don J. Williams
DON J. WILLIAMS
Major, Ord Corps
Chief, Mechanical and Electric
Inspection Equipment Division

ABSTRACT

This report describes the design of an experiment to verify the mechanisms governing the transport of moisture past a rotary seal. The mechanisms were determined after extensive search of the technical literature; consultations with persons knowledgeable in the field of water vapor and related phenomena; and they are presented in Memorandum Report No. M63-1-1 dated January 1963.

Nonexistence of suitable testing facilities required the design and development of special equipments necessary to conduct the experiment. These equipments included special moisture sensors with associated indicating device and suitable sensor calibration means; leakproof chambers for simulating fire control instruments; means for simulating various modes of rotation; and a constant temperature environmental chamber. The testing facilities and their state of completion at the end of FY 1962 are discussed herein. The design, development, procurement and/or fabrication constitute the major effort during FY 1962.

Recommendations to continue the program are made; cost and time estimates for completion of testing facilities and carrying out of experiment are presented.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

INTRODUCTION

Present fire control instruments containing rotary seals are not properly sealed to exclude the inflow of elements harmful to instrument performance (moisture, dirt, dust, spores, fungi growth or other foreign matter). In particular, an effective moisture barrier has never been achieved. This is evident in view of the number of unsatisfactory engineering reports received from the field forces.

The actual form that a rotary sealing system must take (i. e., the properties the system must possess to effect an adequate moisture barrier) was never fully understood by the fire control instrument designer because he was not cognizant of the true mechanisms causing the moisture to flow past the seal. Therefore, if adequate sealing systems are to be realized, it is mandatory that these mechanisms be determined and verified.

Although effort had been expended, prior to this program, concerning parameters that influence the flow of moisture past a rotary seal, and some statistical reasoning developed, [1] it was believed that the intuitive reasoning should be checked with other investigators and that the technical literature should be searched.

Study of previous efforts by investigators, consultations with persons knowledgeable in the field of water vapor and related phenomena, and a search of the technical literature pertaining to the transfer of water and its vapor have taken place. From this survey, augmented by the original intuitive and statistical reasoning, mathematical formulae and flow models for explaining the apparent flow mechanisms were developed. These, plus quantitative engineering estimates of probable moisture flows through actual rotary sealing systems were presented in a technical report. [2] These efforts constituted the first

[1] Interim Test Report No. 1 - FY 60, Appendix A, "Mechanical Computer Components - Task 2 - Sealing of Fire Control Instruments," B. Hoffman, et al., Sep 1959.

[2] Memorandum Report M63-1-1, "Determination of the Mechanisms Governing the Inflow of Moisture Past a Rotary Seal - Theoretical Model," by B. Hoffman, Jan 1963.

phase of the over-all program to determine the mechanisms governing the inflow of moisture past a rotary seal.

Three principal mechanisms that govern the flow of moisture past the rotary seal were determined. These are gaseous diffusion, capillary action (or viscous flow when negative[3] total pressure differentials exist across the seal) and mechanical pumping action due to rotary motion. The first of these mechanisms concerns mass in the gaseous state (water vapor). When no moisture in the liquid state exists, it constitutes the only transport means for penetration of the seal, with the possible exception of gaseous media swept into the instrument by mechanical pumping action of the rotary member. The mechanism is a combined form of Fick's low of gaseous diffusion and Poiseuille's law of gaseous viscous flow so modified that it is comptatible with the boundary conditions and limitations imposed by actual rotary sealing systems. The mathematical expression depicting it is as follows:

$$N_{A(total)} = - \frac{D_{AB}}{R_A T_\ell}\left(pA_2 - pA_1\right) + \alpha\left[\frac{nd^2 gc\, P_{AV}}{32\mu n\ell}\left(P_1 - P_2\right)\right]\frac{p_A^*}{P^*} \text{ --- } \quad (1)$$

(2)

As noted, this mechanism has the environmental elements of total pressure and water vapor partial pressure differentials as the driving forces. The seal geometry is an impedance factor in all mechanisms. The viscous properties of the gaseous media is an additional impedance factor in this mechanism. Both the driving force and impedance are strongly temperature sensitive and therefore the moisture flow is affected by changes in temperature. Because of this fact, experiments designed to verify this mechanism, and the following two mechanisms, will be conducted at constant temperature.

The second of these mechanisms concerns mass in the liquid state and is represented by the following mathematical formulations:

$$N^*_{A(water)} = + \frac{w\pi d^4 gc\,\Delta p}{128\mu_{H_2O}\ell} \quad (2)$$

(4)

---

[3]Negative depicts that the external environmental pressure is greater than the internal instrument pressure.

[4]Also equation (12). Appendix A.

when negative total pressure differentials exist across the seal and by

$$N_A = -\frac{D_{AB}}{R_A T \ell'}\left(pA_2' - pA_1\right) \quad (5) \qquad (3)$$

when positive total pressure differentials exist across the seal. The first of these equations is simply Poiseuille's law of viscous flow of liquids through capillary like flow paths. It has the environmental element of total pressure differential across the seal as the driving force. In addition to the geometry impedance, there is an impedance due to the viscous properties of the liquid water. When positive pressure differentials exist across the seal, capillary action causes the liquid water to move within the seal flow paths a given distance as depicted by the following equations:

$$4T \cos(\theta) - d\Delta p = 0 \quad (6) \qquad (4)$$

when rotary member and seal are in horizontal position and

$$h = -\left(\frac{4T\cos\theta}{dw} - \frac{\Delta p}{w}\right) \quad (7) \qquad (5)$$

when rotary member and seal are in the vertical position. Equation (3) describes the mechanism for the transport of the moisture through the remainder of the flow path into the instrument chamber. This mechanism has the environmental element of water vapor partial pressure differential across the seal as the driving force. The total pressure, the viscous properties of the gaseous media as well as the seal geometry are the impedances.

---

[5] Also equation (8a), Appendix A.

[6] Also equation (13), Appendix A.

[7] Also equation (10), Appendix A.

The third mechanism, mechanical pumping action, may or may not exist. It will be strongly influenced by seal geometry changes due to rotation and to surface conditions of both gasket material and mating rotary member. Because of the random nature of the above, no attempt will be made to assign mathematical formulae to describe it until its presence is verified by experimental results.

This report is concerned with efforts to design a suitable experiment for establishing the validity of the above mechanisms. Since, the major problem in carrying out the experiment is the acquisition of suitable test equipment, this report describes efforts to design, develop, fabricate and/or procure the required facilities.

DISCUSSION

1. Approach

a. Two approaches are possible for designing an experiment to prove the validity of the moisture flow mechanisms. These are: (1) by simulating the rotary seal geometrical flow path configurations (impedance characteristics of the seal) and artificially creating the environmental conditions that are normally imposed upon the seal, and (2) by using actual rotary seals that are presently employed. If the geometrical flow path configurations assumed by actual rotary seals during various modes of usage[8] could be simulated, then the first approach would be more economical and certainly more versatile. However, due to the very strong affect that slight changes in the flow path geometries have upon the characteristics and magnitude of the flow, it would be required that the actual flow path configurations be exactly known and very precisely simulated. Since these configurations are not known, the best that can be expected are assumed configurations, and it was considered wiser to pursue the second possible approach, i. e., use an actual rotary seal. Because "O"-rings are

[8]Modes of usage include storage conditions (nonrotary motion) and various types and frequencies of angular motion.

the most generally used rotary seal in fire control instrument application, and because the most reliable apriori data exists, it was decided that the "O"-ring would be the best representative seal for experimental purposes. The results will be correlatable to other rotary seal systems.

b. A successful design of experiment for verifying the moisture flow mechanisms was contingent upon the premise that three conditions could be satisfactorily met:

(1) That a sufficiently sensitive and precise humidity measurement device could be obtained that would be capable of sensing accurately and repeatedly very small changes in moisture build-up expected to take place during a reasonably short test period.

(2) That test chambers for simulating fire control instruments containing rotary seals could be economically designed and fabricated with leakage characteristics restricted to no more than 5 percent of the estimated [2] leakage through the rotary seals whose leakage characteristics are to be evaluated.

(3) That an environmental test chamber for maintaining a very constant temperature at a given desired relative humidity condition could be economically obtained (designed, fabricated and/or procured) and economically employed during test periods.

c. Based upon practical solutions to b(1) through b(3), a detailed design of experiment can then be formulated; hardware designed, fabricated and/or procured; and utilizing these testing equipments, the experimental verification can be performed.

2. Proposed Methods of Solution for Conditions to be Met

A degree of interdependence exists among the conditions to be satisfied. Considered solutions to each condition must recognize the limitations imposed by the probable solutions to the others. Solutions to these three conditions are as follows:

a. Obtainment of a Sufficiently Sensitive and Precise Moisture Measuring System

A survey was made of existing commercial and laboratory methods for measuring humidity and the availability of instrumentation

for carrying out these methods. No commercial or laboratory method (in its existing embodiment) was found suitable for meeting the very precise sensitivity and accuracy requirements and still meet limitations imposed by test chamber requirements. A moisture sensor was finally located (Aminco-Dunmore Sensing Element) that has the desired sensitivity and stability, but requires that temperature of measured gas be held constant within very narrow limits and that a very stable, precise, and sensitive indicating device be employed in the measurement system. The results of this survey and a decision to employ the Aminco-Dunmore moisture sensing element are covered in Reference 1. Two possible indicating systems were considered, and as a result of the evaluation, the system employing a Wayne-Kerr conductance bridge was adopted. Results of this evaluation and a decision to employ Wayne-Kerr conductance bridge are discussed in Reference 2. A major problem arose when the moisture sensor supplier (Hygrodynamics, Inc.) was unable to adequately provide the various stable environmental humidity conditions and accurately measure them during attempts at calibrating the sensors. This unexpected situation imposed an additional requirement of providing adequate calibration means. An investigation ensued concerning methods of generating constant relative humidities of known amounts useful for calibration of the sensors in the humidity range of interest (2.55 to 14.0% at a dry bulb temperature of 60° F). A decision was reached to use a basic method developed by the National Bureau of Standards known as the two pressure method (see NBS Circular No. 512 dated 28 Sep 1951). Results of the investigation and decision to employ the two pressure system are discussed in Reference 3. Therefore, by using the Aminco-Dunmore sensing element calibrated by above NBS system and employing a Wayne-Kerr bridge, condition 1 has been satisfactorily met.

b. Design of Leakproof Test Chambers for Simulating Fire Control Instruments

Lack of sufficient engineering data concerning test cell joint construction generated the need to conduct system leakage tests on simulated test chambers using various types of joint constructions. These joint constructions were (1) three "O"-ring type (see figures 1 and 2), (2) shrunk and soldered joints (see figure 2), (3) "O"-ring and mercury seal (see figures 3 and 4), (4) metal-to-metal joint secured by heavy strap force through needle bearings (see figure 5), and (5) three "O"-ring type using special clamping device (see figure 6). The results of these evaluations are depicted in Appendix B. As noted in the appendix, the three "O"-ring joint construction, using

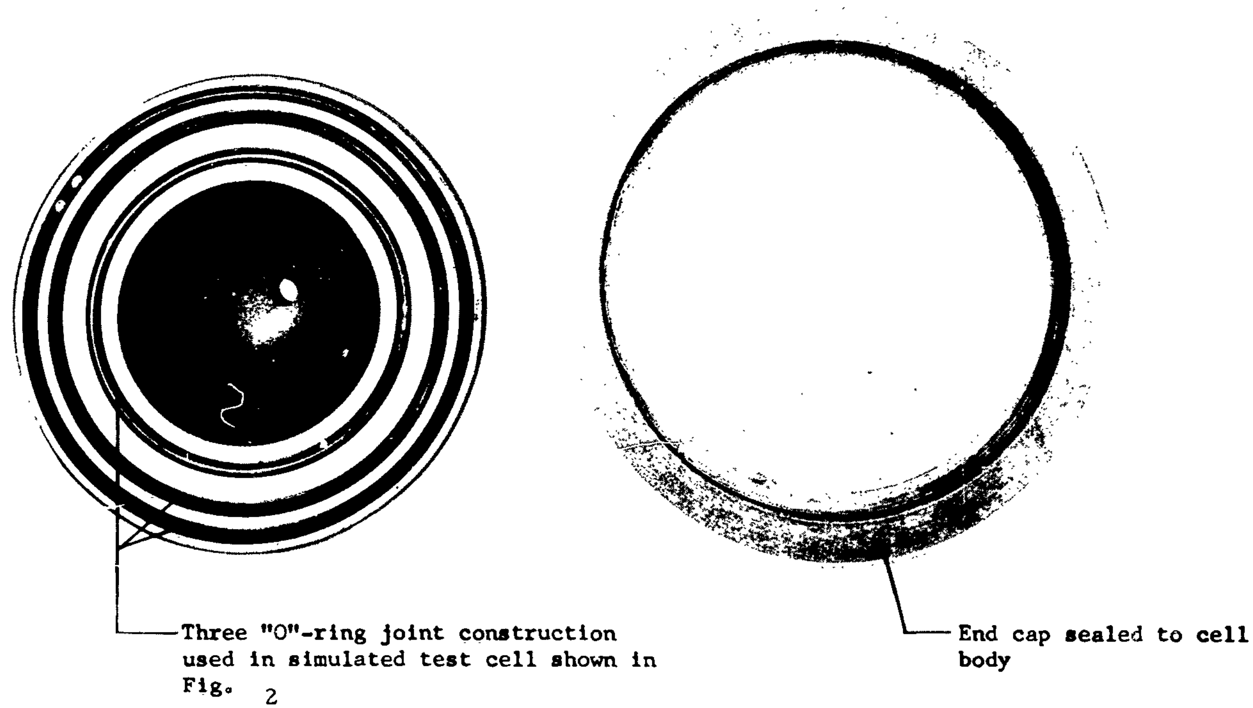
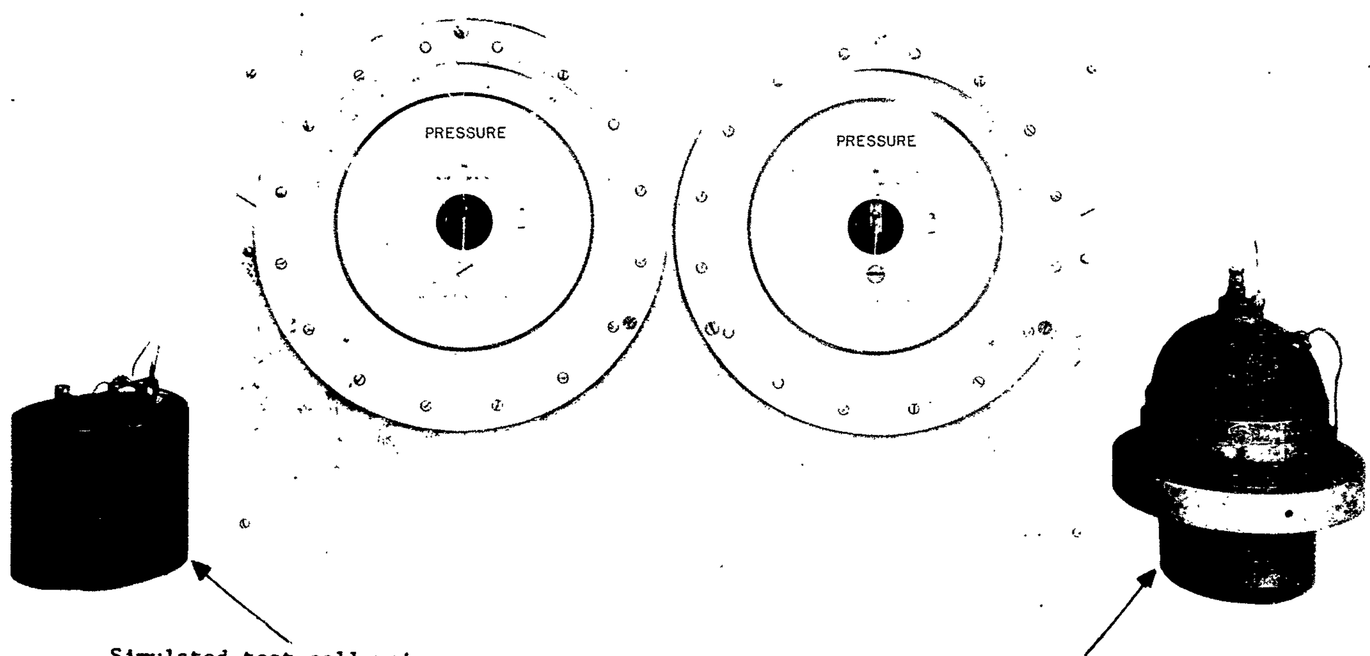


Figure 1. Test Cell System Leakage Determination Tests Using Various Joint Constructions (Three "O"-ring Joint Construction)

DETERMINATION OF LAW GOVERNING INFLOW OF MOISTURE THROUGH A ROTARY SEAL



Simulated test cell using shrunk and soldered joints

Simulated test cell using "O"-ring joints

Figure 2. Test Cell System Leakage Determination Tests Using Various Joint Constructions ("O"-ring, and Shrunk and Soldered Joints)

DETERMINATION OF LAWS GOVERNING INFLOW OF MOISTURE THROUGH A ROTARY SEAL

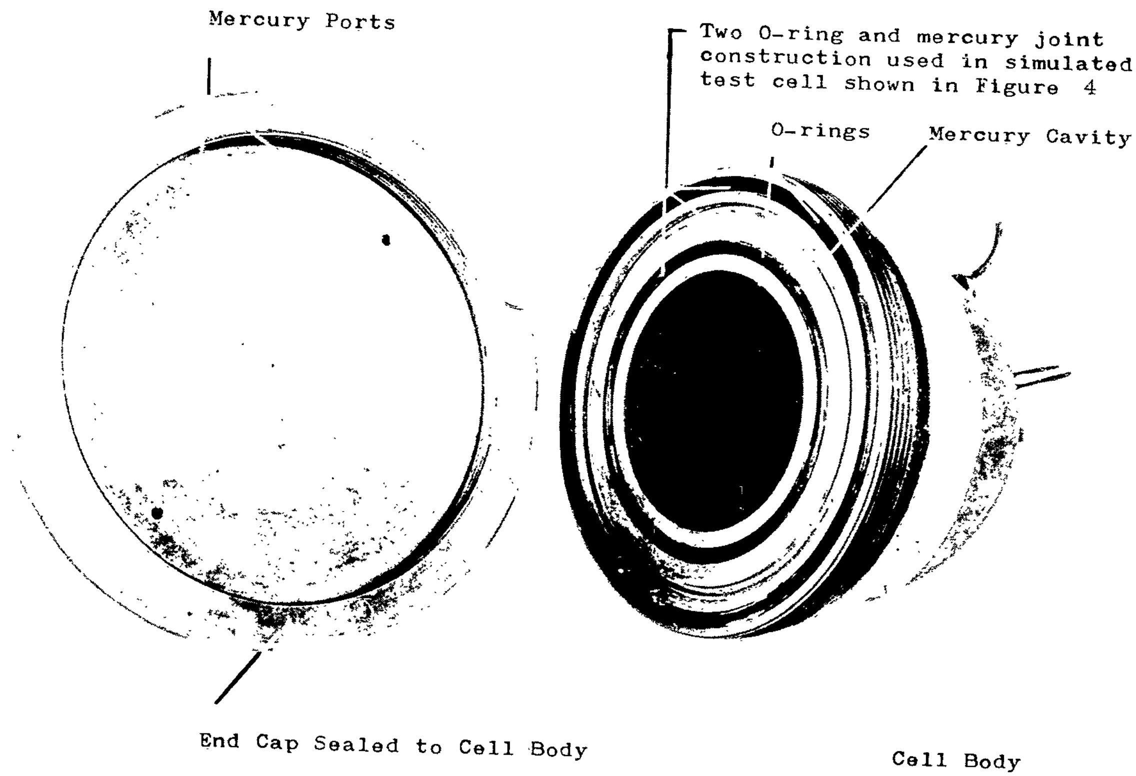


Figure 3. Test Cell System Leakage Determination Tests Using Various Joint Constructions ("O"-ring and Mercury Joint Construction)

Mercury inlet port

Simulated test cell using O-ring and mercury joint construction

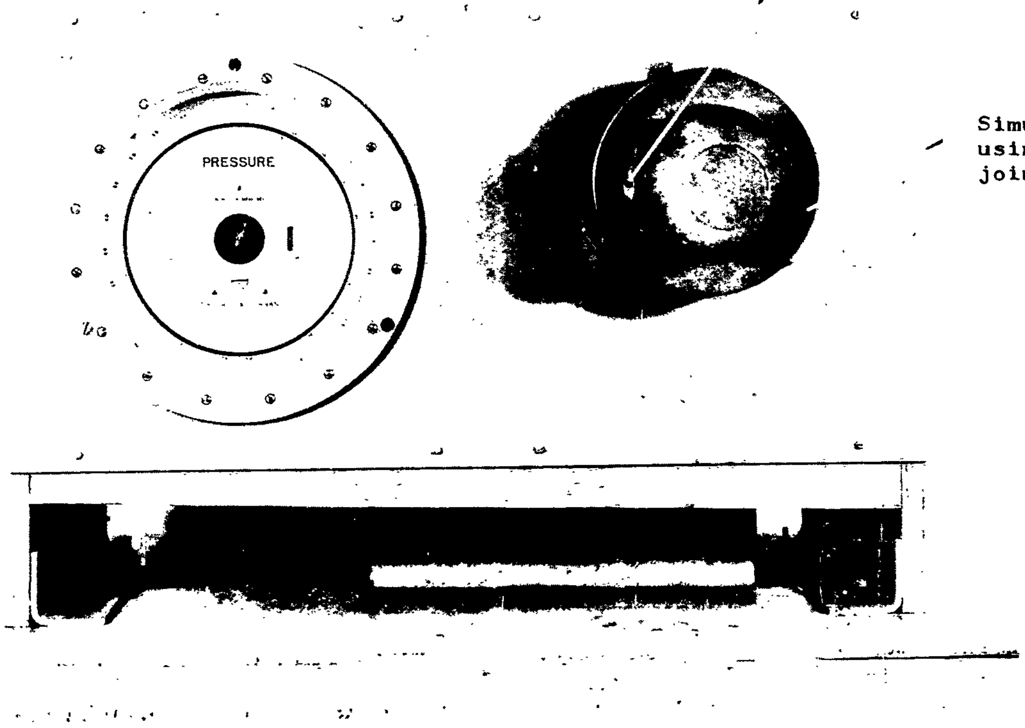


Figure 4. Test Cell System Leakage Determination Tests Using Various Joint Constructions (Simulated Test Cell, "O"-ring and Mercury Joint Construction)

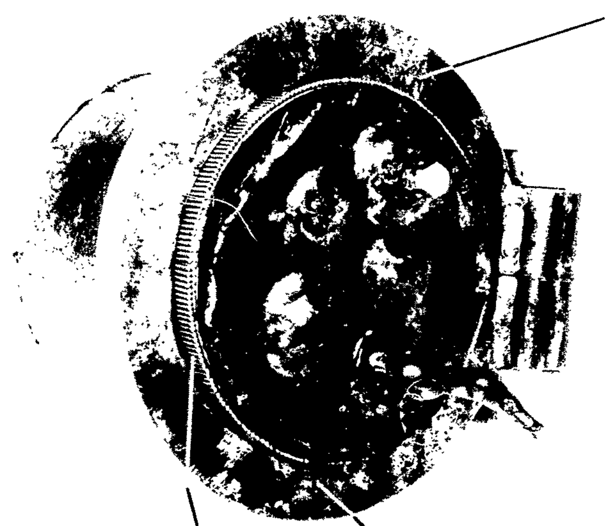


Figure 5. Test Cell System Leakage Determination Tests Using Various Joint Constructions (Metal-to-Metal Joint Construction)

Figure 6. Test Cell System Leakage Determination Tests Using Various Joint Constructions (Special Adapter - "O"-ring Joint)

special clamping device, and the shrunk and soldered joint construction produced leakage rates below a target value of 0.500 $in.^3$/year-psi. Therefore, data provided by these tests and the successful solution to condition 1 created the preliminary requirements for finalization of a leakproof test chamber design. Condition 2 has been satisfactorily met.

c. Design of Economical Environmental Test Chamber for Maintaining Very Constant Temperature at Given Desired Relative Humidity

Geometrical considerations of the finally chosen leakproof test chamber configurations; total number of test chambers required in design of experiment; and the tight environmental temperature requirement of the moisture sensors collectively generate the requirements imposed upon the environmental test chamber. The initial intended operating conditions for the program are: 60° F constant temperature at fixed barometric pressure and 85% R. H; 60% R. H; or 30% R. H. Once having established the experimental procedures at this temperature, other fire control instrument temperature conditions will be considered. Unfortunately, no suitable environmental test chambers meeting program temperature regulation requirements are available at Frankford Arsenal. Furthermore, economics prohibits the use of Frankford Arsenal's equipment. The temperature stability of the test cells is achieved as follows. The test cell is surrounded with the proper gaseous environment, and the cell and its environment are immersed in a fluid with large heat inertia. If the temperature of the fluid is accurately controlled and the heat transfer between the fluid and the cell environment maximized, then the relatively low heat content of the environment would be effectively controlled by the large heat inertia of the surrounding fluid. The thick walls of the test cell would act as a damping medium and greatly attenuate any variations. Further, the very small heat transfer film coefficient between the test cell walls and its internal gas will cause a large time constant to exist. This will greatly attenuate temperature variations within the gas so that the internal gas temperature will stabilize at some average value of the wall temperature.

The first system design concept that was conceived consisted essentially of a large cylindrical water tank (with the means for controlling the water temperature) into which was submerged an airtight, hermetically sealed chamber. This chamber contained adequate means for both generating and controlling required environmental

humidity conditions and for circulating the air. The top of the chamber was to have an airtight access lid through which the leakproof test chambers would be placed within the airtight environmental chamber. Such a system was discussed with Frankford Arsenal Plant Engineering, the results of which are contained in Reference 4. Means of developing a minimal cost system were investigated. A final system concept has been developed. This system utilizes the special two pressure system moisture sensor calibrator in its entirety. The calibrator functions both as the generator of the desired humidity environment and as the controller of the desired water temperature. This dual use of the calibration equipment simplifies the required system and reduces its cost. Therefore, using the final concept, condition 3 has been satisfied.

3. Design, Fabrication and/or Procurement of Physical Testing Facilities

a. Moisture Measuring System

Three overlapping range Aminco-Dunmore sensing elements are used. To gain a statistical assurance that the elements do not change calibration during test, three elements for each range are incorporated, i.e., nine elements for each test cell. As five test chambers are required, 45 elements are employed and have been procured. A Wayne-Kerr conductance bridge (see figure 7) was procured and satisfactorily tested. A complete integrated system has been designed, a schematic of which is shown in figure 8.

b. Calibration System for Moisture Sensors (NBS Two Pressure Method)

Initially, it was believed that either the sensors could be sent to an installation possessing an NBS system and be calibrated there, or that an adequate system might be procured economically as an entity by itself with calibration being performed at Frankford Arsenal. It became necessary, because of economics and nonavailability of a ready-made system (in the desired humidity range), to design a system (see figure 9). This design was adopted and all necessary components were procured and checked out for compliance with specifications. With the exception of fabrication of some minor parts and assembly of all components, the system is complete.

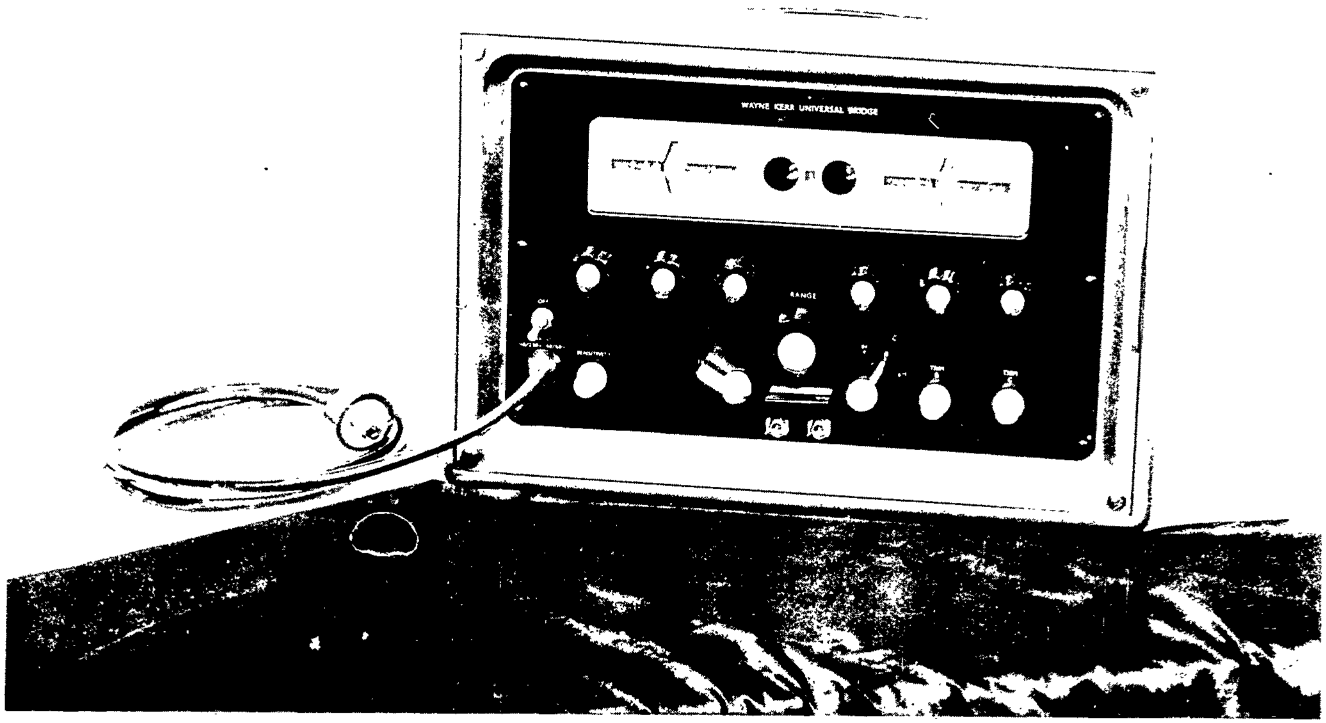


Figure 7. Wayne-Kerr Conductance Bridge

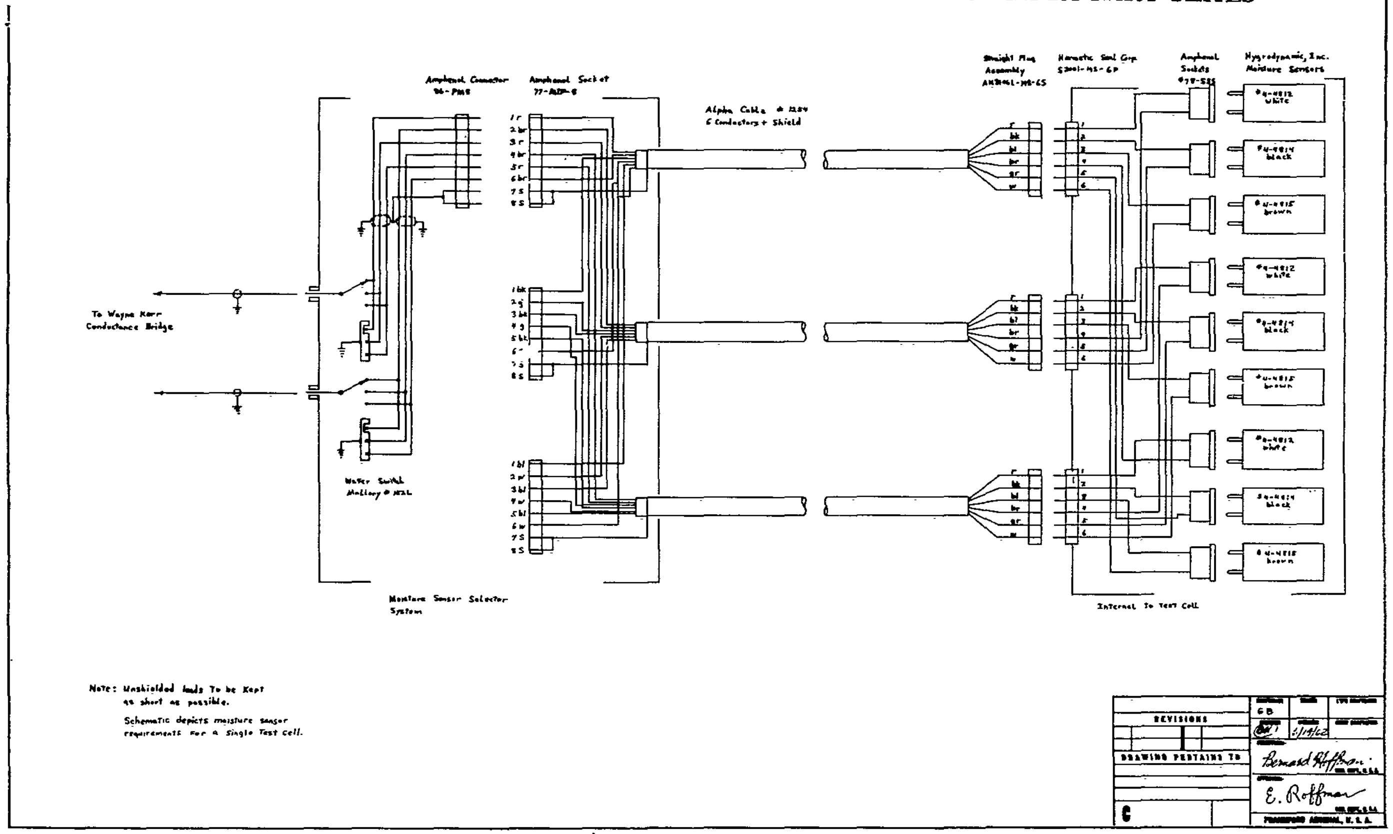
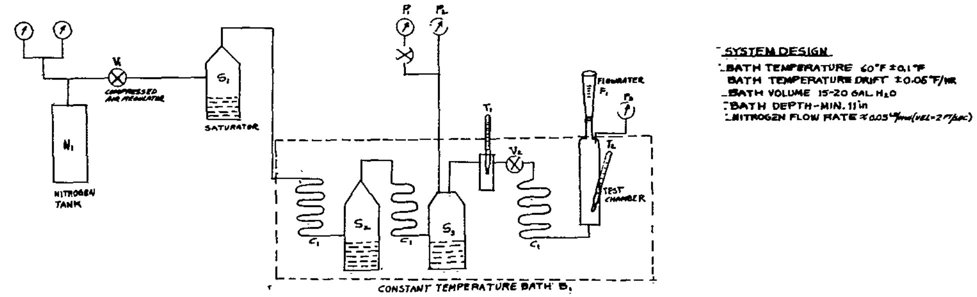


Figure 8. System for Measuring Moisture Vapor Internal to a Test Cell

DETERMINATION OF THE MECHANISMS GOVERNING INFLOW OF MOISTURE THROUGH A ROTARY SEAL



SYMBOL	COMPONENT	MODEL TYPE	PRICE	DELIVERY	SOURCE	ACCURACY
N_1	COMPRESSED NITROGEN	2200 psi Tank-224 ft³	$155/100 FT³	STOCK	AIR REDUCTION SALES CO	—
S_1, S_2 & S_3	SATURATOR	HIGH PRES BOTTLE	$2.50/each	15 DEC 61	A.G. JAFFE, INC	—
P_1	PRESSURE GAGE	FA-23414	$310	15 MAR 62	WALLACE & TIERNAN	0.1%
P_2	PRESSURE GAGE	FA-141700	$170	15 MAR 62	WALLACE & TIERNAN	1/3% Full Scale
P_3	PRESSURE GAGE	0-1000 psi	$264.50	15 MAR 62	HEISE BOURDON TUBE CO, INC	0.1%
F_1	FLOWRATOR	[illegible]	[illegible] $72.00	15 JAN 62	FISCHER AND PORTER CO	2%
C_1	COPPER COILS	1/8" Dia. Ref Tubing	[illegible] $13.60	30 DEC 61	AIRFLOW CO.	—
V_2	FLOW CONTROL VALVE	No. 162 with No. 3V tip	[illegible]	29 JAN 62	FLOW SYSTEMS, INC.	—
V_1	PRESSURE REGULATOR VALVE	—	$30			
T_1 & T_2	PREC. BOMB CALORIMETER THER	SPEC. No. 21529 [illegible]	[illegible]	29 FEB 62	TAYLOR INSTRUMENT CO	0.05°F at any point
B_1	REFR. CONSTANT TEMP BATH	[illegible]	$1150.00	6 APR 62	FGRAIA SCIENTIFIC, INC	[illegible]

REVISIONS

DRAWING PERTAINS TO

Figure 9. Schematic Diagram-Aiming-Dunmore Humidity Sensor Calibration Unit

c. Design and Fabrication of Leakproof Test Chambers

The successful solution to condition 1, as well as engineering data generated concerning adequate chamber joint construction, created the preliminary requirements for the test chamber design. The next step in the chamber design was to consider other aspects for assuring a successful design of experiment. It is essential to incorporate in the design of experiment as many controls, economically as possible, to minimize random variations of nontested parameters which might also influence the rate of inflow of moisture through the rotary seal. Thus, the confidence level of test data is appreciably increased. Slight changes in flow path geometries have a very strong affect upon the magnitude and characteristics of the moisture flow. Hence, it is most important that each of the rotary seals tested in the leakproof test chambers have essentially the same flow path geometries to assure as high a confidence level in test results as possible. Unfortunately, apriori data do not exist as to the weighted affects on flow characteristics of manufacturing tolerance variations permitted in the fabrication of the rotary seals. Appendix C discusses some of the nontested parameters which might influence the rate of inflow of moisture by causing significant changes in the flow path geometry and which have variations permitted through normal manufacturing tolerances.

It is not the intent of this program to investigate variations in these parameters, as such an investigation would be a mammoth undertaking. The manufacturing tolerances must be tightened in recognition of the possible influence of these variables. Other considerations in the design of the test chambers were the statistical sample size of "O"-rings per test chamber, the volume size and the number of test chambers to be employed during test. The decisions concerning the tightening of tolerances and the other considerations are discussed in Appendix D. The various controls in the design of experiment were considered, and a final leakproof test chamber design was formulated (see figures 10 and 11). This design includes means for simulating various modes of rotation. All components of the leakproof test chambers were fabricated and subassembled. Proof of nonleakage test of the final chamber design has been completed and the design proved to be sound. Tasks still remaining are the assembly of the various components and subassemblies into the completed leakproof test chamber units.

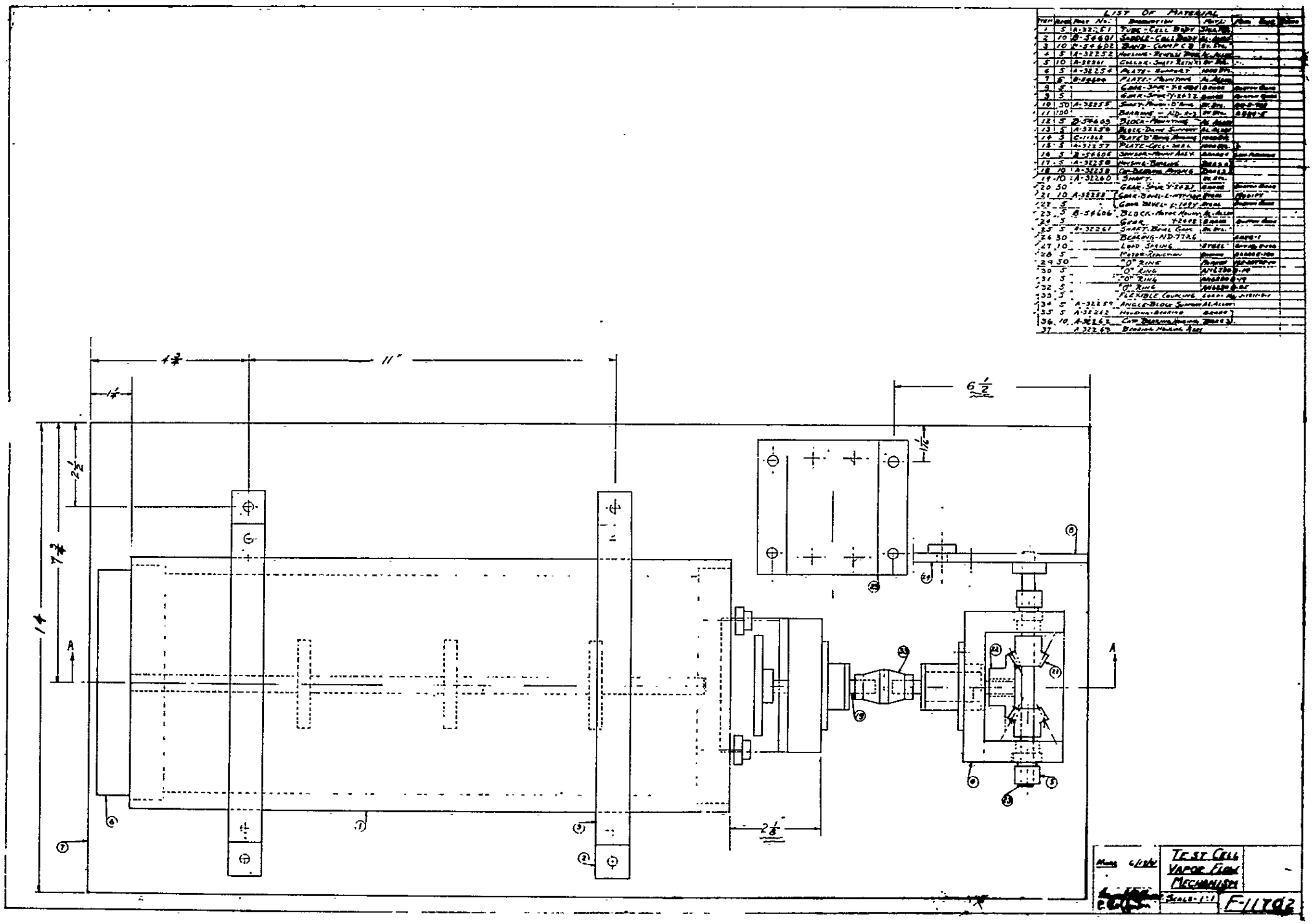


Figure 10. Test Cell-Vapor Flow Mechanism

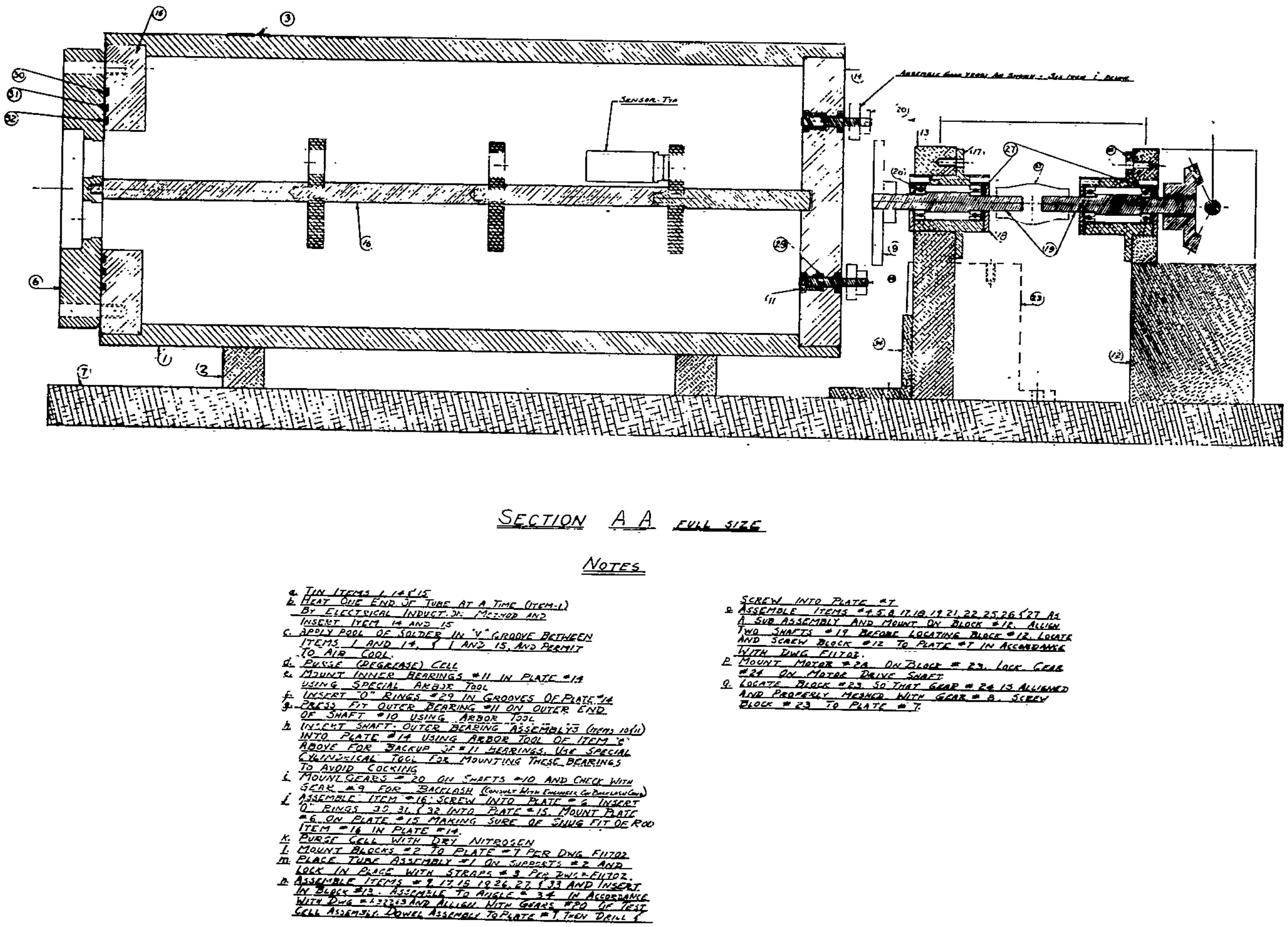


Figure 11. Test Cell-Vapor Flow Mechanism (Section AA)

d. Design of an Environmental Chamber for Maintaining Very Constant Temperature at Given Desired Relative Humidity

A final system concept has been developed which utilizes the special two-pressure system moisture sensor calibrator in its entirety. A schematic of this system is shown in figure 12. Tasks remaining include the detailed design of chamber, procurement of a cylindrical water tank, airtight hermetically sealed gas chamber and other associated hardware, and the assembly of the components into an integrated unit.

4. Design of Experiment

Experimental efforts to verify the flow mechanisms will consist of the following:

a. Verification of the Modified Combined Form of Fick's Law of Gaseous Diffusion and Poiseuille's Law of Gaseous Viscous Flow (equation 1)

The five leakproof test chambers will first be thoroughly purged with dry nitrogen gas (dew point temperature of -25° F) and then each charged to a different total absolute pressure level, some below and some above the ambient barometric pressure. This procedure will be repeated each time for a series of test runs to be performed in the special environmental chamber at different relative humidities but at the same environmental temperature. The relative humidities to be employed will range from 30 to 85 percent at a constant temperature of 60° F, and with care being exercised that no condensation occurs due to localized cooling. Also, throughout the series of test runs, a fixed mode of rotation of shafts will be employed. Each test run will be sufficiently long to enable several moisture content readings per test chamber, each after a fixed period of time. The data generated, when properly correlated, should provide sufficient information to investigate and verify all the driving force and impedance terms of equation (1). Verification of the influence of variation of temperature on flow rate can be considered for future extension of the present program. It will require recalibration of moisture sensors for each temperature and little or no modification of the present equipment.

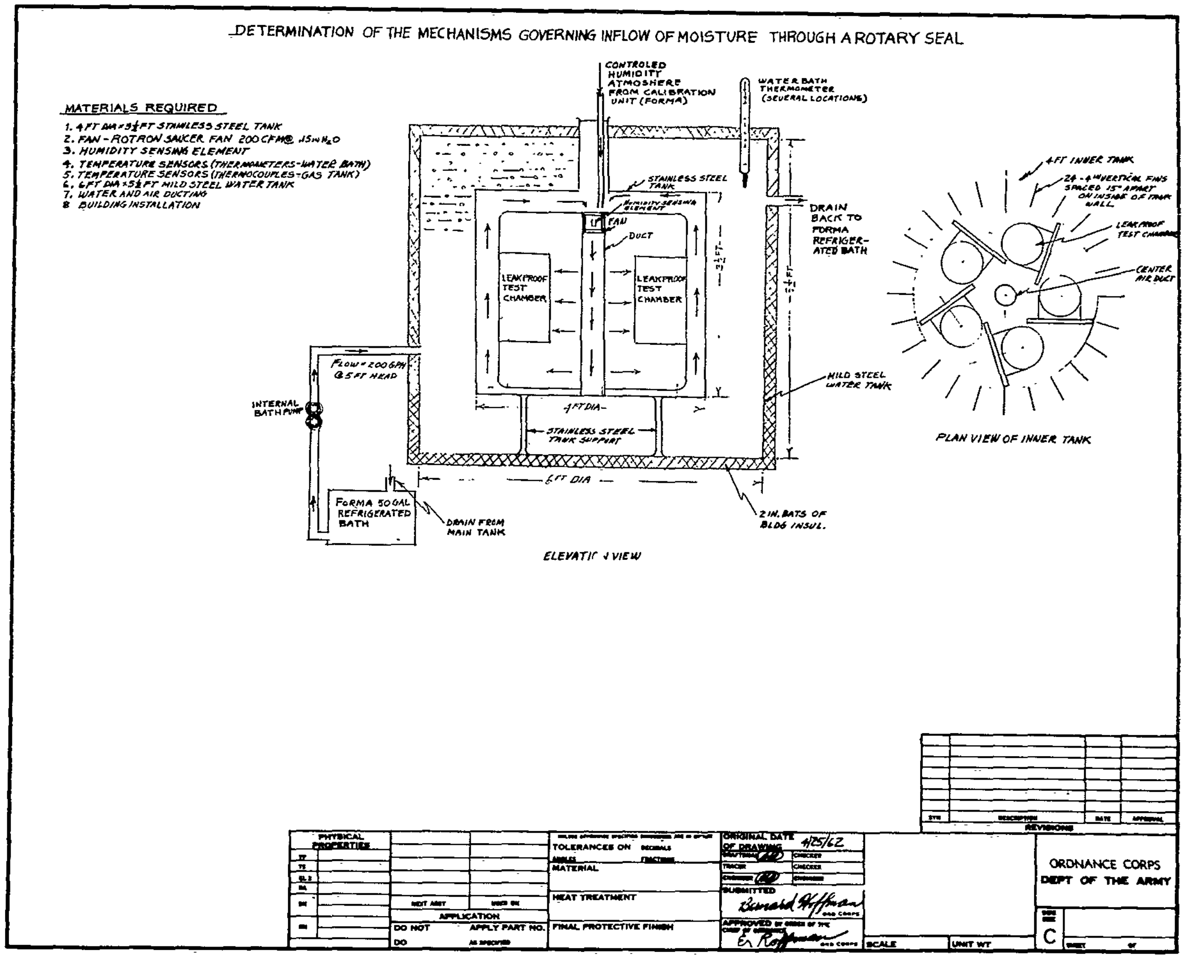


Figure 12. Schematic-Environmental Chamber (Very Constant Temperature at Given Relative Humidity)

b. Verification of Equimolal Gaseous Diffusion (Equation 3)

This mechanism concerns mass in the liquid state. It occurs when positive total pressure differentials exist across the seal and after capillary action causes liquid water to move within the seal flow paths. The capillary flow distances are as depicted by either equations (4) or (5), depending on whether rotary member and seal are in a horizontal or vertical position. Fick's law of equimolal gaseous diffusion constitutes the mechanism for the transport of the moisture through the remainder of the flow path.

Experimental efforts to verify equation (3) will be conducted after completion of a. above and will consist of purging and pressurizing the leakproof test chambers in the manner previously described. Each chamber will be maintained at a positive total pressure differential. An adaptor piece (see figure 13) will be affixed to the front of each test chamber and filled with water. This permits the external portion of each rotary "O"-ring seal to be completely in contact with liquid water. The leakproof test chambers will then be placed in the special environmental chamber in a vertical position (see figure 12) and a test run made at 60° F. No attempt will be made to control the relative humidity. Again, the same fixed mode of rotation will be employed and the test run will last long enough to enable several moisture content readings per test chamber to be made. The data generated concerns seal and shaft in a vertical position and when related to equation (5) and properly correlated, should provide sufficient information to investigate and verify all the driving force and impedance terms of equation (3). All the leakproof test chambers will then be removed from the environmental chamber. Two of the test chambers will be repurged and repressurized to total pressure levels identical to their previous values and then placed in the special environmental chamber in a horizontal position (by use of adaptor plates). A test run will be made under similar conditions. The data obtained in the horizontal position when related to equation (4) should provide sufficient information to investigate and verify all the driving force and impedance terms of equation (3). The only difference between the results to be obtained when the test chambers are in the horizontal or vertical position would be the length of flow path as predicted by equations (4) and (5).

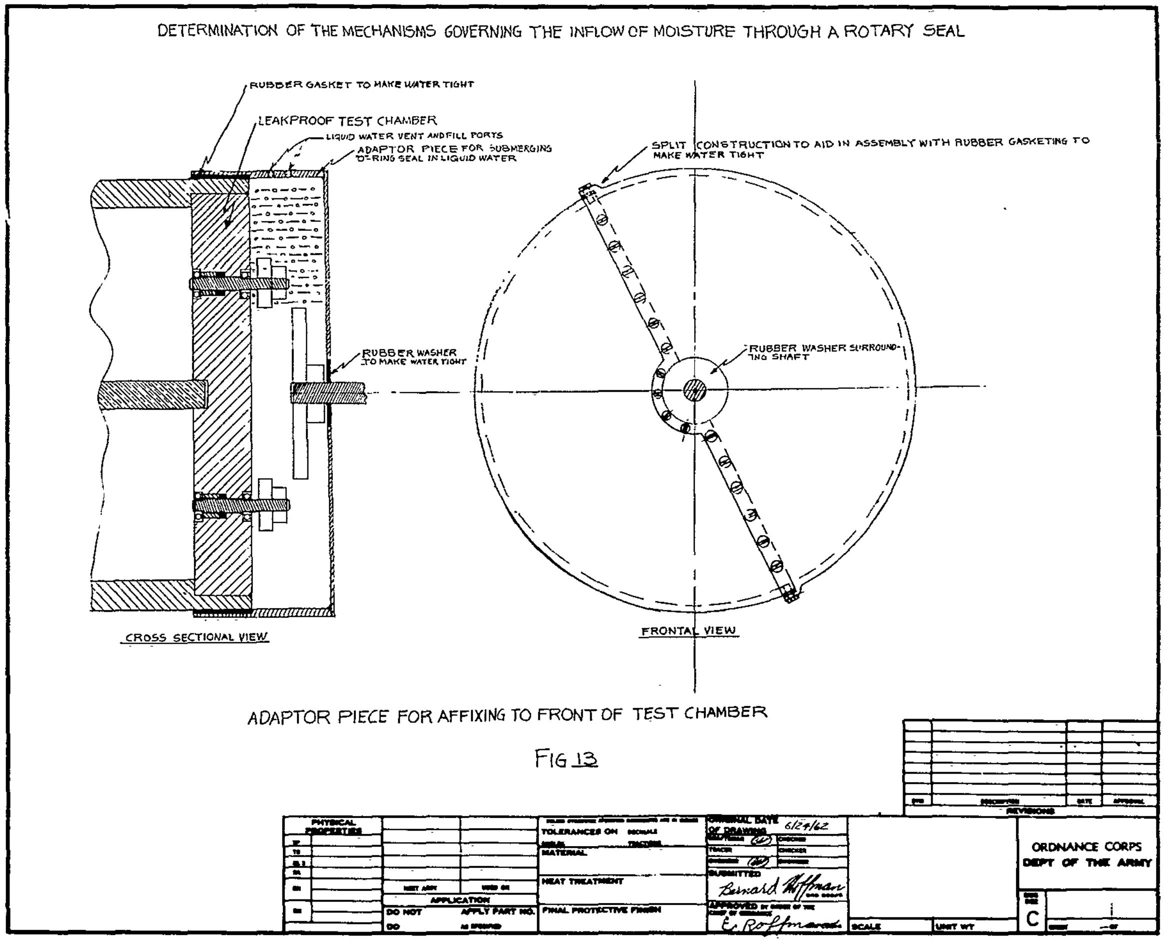


Figure 13. Adaptor Piece for Affixing to Front of Test Chamber

c. Verification of Poiseuille's Law of Viscous Flow of Liquids Through Capillary Like Flow Paths (Equation 2)

This mechanism concerns mass in the liquid state and occurs when negative pressure differentials exist across the seal.

Experimental efforts to verify equation (2) will be conducted after completion of b. above and will consist of purging and pressurizing the leakproof test chambers as depicted in b., but with chambers maintaining a negative pressure differential. Again, the adaptor piece (see figure 13) will be affixed to front of each test chamber and filled with water. The test chambers will then be placed in the special environmental chamber in a vertical position[9] and a test run made at 60° F. Again, no attempt will be made to control the relative humidity. The same fixed mode of rotation will be employed and several moisture readings will be taken. The data generated should provide sufficient information to investigate and verify all the driving force and impedance terms of equation (2).

d. Investigation of Mechanical Pumping Action Due to Rotary Motion as a Possible Moisture Flow Mechanism

Care was taken in all of the above experimental efforts to rotate the shafts in the same fixed mode. This was to assure that any pumping action due to the rotary motion that might develop had a constant value. After all of the test runs in a. through c. above are completed and prior to taking the runs off the line, a testing period will be devoted to changing the mode of rotation. Various modes at different angular velocities will be used in an attempt to discern differences in moisture flow rates that might be attributed to the pumping action mechanism. At this time an attempt will be made to develop a logical mathematical formulation.

[9] The mechanism depicted by equation (2) is independent of position.

SUMMARY OF RESULTS AND CONCLUSIONS

1. An approach for design of experiment has been chosen initially utilizing rotary "O"-rings as the vehicle for proving out the moisture flow mechanisms. The mechanisms were determined after a theoretical investigation and are outlined in a Memorandum Report.[2]

2. The feasibility of a successful design of experiment is contingent upon the premise that three conditions (1) obtainment of adequate moisture measuring system, (2) design of leakproof test chambers, and (3) obtainment of adequate and economical environmental test chamber could be satisfactorily met. Since these conditions have been met, a design of experiment was formulated. A flow chart illustrating the total program is shown in figure 14.

3. All major problems associated with selection of equipments and design considerations have been solved.

4. Status of Testing Facilities:

a. Design

All major equipments have been designed. The detail design of the environmental chamber will be completed.

b. Fabrication

The following items still remain to be built:

(1) Minor parts of calibration system.

(2) Installation of cabling from moisture measuring system indicator to test chambers and calibration of sensors.

(3) Fabrications of necessary components to allow assembly of environmental chamber into an integrated unit.

c. Procurement Remaining

(1) Cylindrical water tank for environmental chamber.

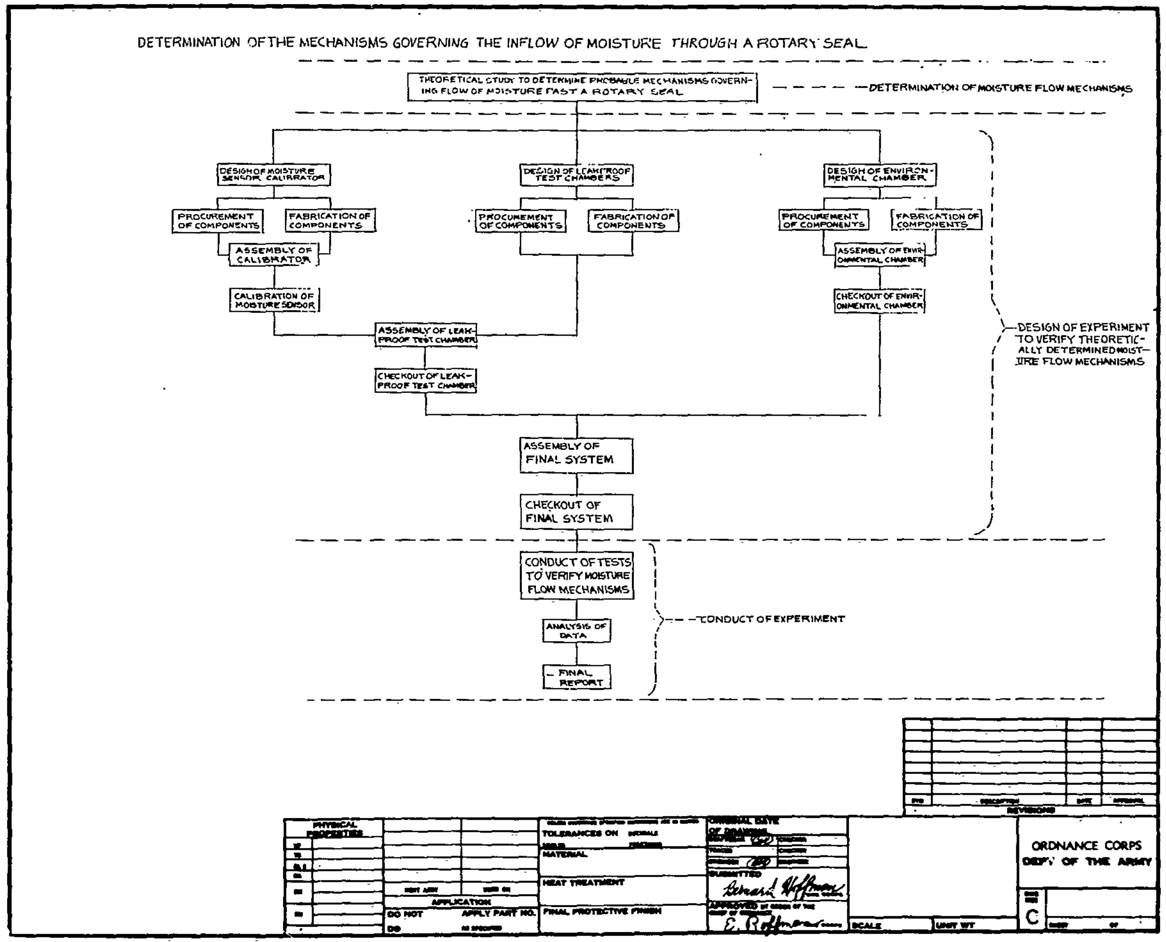


Figure 14. Flow Chart - Program for Determination of Flow Mechanisms Governing Flow of Moisture Past a Rotary Seal

(2) Airtight hermetically sealed gas chamber and associated hardware.

5. A time and cost estimate to complete the program follows:

		Personnel (man months)			
		Design	Tech	Engr	Cost
I	Design	2.0	0	0.25	$ 5,500
II	Fabrication and assembly of equipment	0	7.2	2.50	16,000
III	Procurement	0	0	0.50	6,000**
IV	Calibration and checkout	0	3.2	2.50	9,500
V	Test	0	4.0	1.75	9,500
VI	Evaluation	0	0	1.50	2,500
VII	Report	0	0	1.75	4,500*
	TOTAL	2.0	14.4	10.75	$53,500

*Includes cost of publication

**Includes cost items to be procured

6. The importance of the problem of properly sealing fire control instruments has been covered in this report and in other areas. A substantial effort has been expended by the Army Ordnance Corps for the past 15 years with little or no evidence of a tangible solution. A study of the problem on a basic level (i.e., investigate the actual mechanisms causing the moisture flow) was never attempted previously.

The proposed experiment should provide the basic vehicle for an ultimate solution of this critical problem and form the basis for the solution of similar problems in related areas as well.

APPENDIX A

MATHEMATICAL FORMULAE DESCRIBING PRINCIPAL MECHANISMS GOVERNING INFLOW OF MOISTURE PAST A ROTARY SEAL

Modified combined form[2] of Fick's law of gaseous diffusion and Poiseuille's law of gaseous viscous flow.

$$N_{A(total)} = -\frac{D_{AB}}{R_A T \ell}\left(p_{A_2} - p_{A_1}\right) + \alpha\left[\frac{nd^2 gc P_{AV}}{32\mu_N \ell R_N T}\left(P_1 - P_2\right)\right]\frac{p_A^*}{P^*} \qquad (9)$$

where:

α = Shape factor to correct for the assumed linear average value of P_A^*

$N_{A(total)}$ = Water vapor flow rate/unit area.

D_{AB} = Diffusivity of water vapor through nitrogen gas

R_A = Gas constant for water vapor

T = Absolute temperature

ℓ = Length of capillary tube

p_{A_1} = Internal water vapor partial pressure

p_{A_2} = External water vapor partial pressure

p_A^* = Average water vapor partial pressure

$$\cong \frac{p_{A_1} + p_{A_2}}{2}$$

n = Number of capillary tubes

d = Diameter of capillary tubes

gc = Gravitational constant

μ_N = Absolute viscosity of N_2 gas

R_N = Gas constant for N_2

P_1 = Total internal instrument pressure

P_2 = Total external instrument pressure

$$P_{AV} = \frac{P_1 + P_2}{2}$$

$$P^* \cong P_{AV}$$

Fick's law of equimolal gaseous diffusion[2]

$$N_A = - \frac{D_{AB}}{R_A T \ell'} \left(p_{A_2}' - p_{A_1} \right) \qquad \textbf{(8a)}$$

where:

N_A = Water vapor flow rate/unit area

D_{AB} = Diffusivity of water vapor through nitrogen gas

R_A = Gas constant for water vapor

T = Absolute temperature

ℓ' = Length of reduced flow path

p_{A_2}' = Saturation vapor partial pressure at absolute temperature (T)

p_{A_1} = Internal water vapor pressure

d' = Increased average diameter of capillary

Poiseuille's law of viscous flow of liquids through capillary like flow paths[2]

$$N^*_{A_{water}} = -\frac{w\pi d^4 gc\,\Delta p}{128\mu_{H_2O}\ell} \qquad (12)$$

where:

$N^*_{A_{water}}$ = Liquid water flow rate/unit area

w = Specific weight of liquid water

d = Diameter of capillary

gc = Gravitational constant

μ_{H_2O} = Absolute viscosity of liquid water

ℓ = Flow path length

$\Delta p = P_1 - P_2$ = Differential total pressure across seal

Formula expressing rise of liquid water in capillary tube due to surface tension[2] (Rotary member and seal in vertical position)

$$h = -\left(\frac{4T\cos\theta}{d\cdot w} - \frac{\Delta P}{w}\right) \qquad (10)$$

where:

h = Rise of liquid water column in capillary tube

T = Surface tension of water and N_2 gas

θ = Angle meniscus makes with vertical

d = Diameter of capillary tube

w = Specific weight of liquid water

$\Delta P = P_1 - P_2$ = Differential total pressure across seal

Formula expressing distance liquid water flows through capillary tube due to surface tension (Rotary member and seal in horizontal position)

$$4T \cos \theta - d \cdot \Delta p = 0 \tag{13}$$

where:

T = Surface tension of water and N_2 gas

θ = Angle meniscus makes with horizontal

d = Diameter of capillary tube

$\Delta p = P_1 - P_2$ = Differential total pressure across seal

APPENDIX B

SYSTEM LEAKAGE TESTS ON SIMULATED TEST CHAMBERS USING VARIOUS TYPES OF JOINT CONSTRUCTION

Lack of engineering data concerning adequate test cell joint construction generated the need to conduct system leakage tests on simulated test chambers using various types of joint construction. Results of these tests are as follows:

Three "O"-ring Joint Construction (see figures 1, 2 and 6)

Initial configuration as depicted in figures 1 and 2 discarded because of high leakage. Test results are as follows:

Date Hour	Time θ-Days	P_1 "Hg	B_1 "Hg	T_1 °F	$P_1 + B_1$ "Hg	$T_1 + 460$ °R	$\frac{P_1 + B_1}{T_1 + 460}$	P_2 "Hg	p_2 "Hg	p_2^* psi
1-6-61 1530	0	22.10	30.11	71.0	52.21	531.0	0.09832	52.60	22.68	11.14
1-20-61 1330	13.92	20.99	29.73	70.3	50.72	530.3	0.09564	51.17	21.25	10.43
1-23-61 0900	16.73	20.27	30.16	69.8	50.43	529.8	0.09519	50.93	21.01	10.32
1-25-61 1400	18.94	19.67	30.66	69.0	50.33	529.0	0.09514	50.90	20.98	10.30

Where:

$$P_2 = \frac{P_1 + B_1}{T_1 + 460} \times 535, \text{ "Hg}$$

$$p_2 = (P_2 - 29.92) \text{ "Hg}$$

$$V = 21.21 \text{ in.}^3$$

$$B_s = 14.7 \text{ psi}$$

$$K = \frac{B_s}{V} \text{ psi/in.}^3$$

$$a^{(1)} = \frac{2.3\left[\text{Log } p^*_{2_1} - \text{Log } p^*_{2_2}\right]}{\Delta\theta \cdot K} \times 365, \text{ in.}^3\text{/year-psi}$$

$$a = \frac{2.3\left[\text{Log } 11.14 - \text{Log } 10.30\right]}{\left(18.94\right)\frac{(14.7)}{21.21}} \times 365$$

$$= \frac{(2.3)(0.03405)(21.21)(365)}{(18.94)(14.7)}$$

$$a = \underline{2.18 \text{ in.}^3\text{/year-psi}}$$

New configuration employing special clamping device (see figure 6)

Date Hour	Time θ-Days	P_1 "Hg	B_1 "Hg	T_1 °F	$P_1 + B_1$ "Hg	$T_1 + 460$ °R	$\frac{P_1 + B_1}{T_1 + 460}$	P_2 "Hg	P_2 "Hg	P_2^* psi
2-20-61 1530	0	21.53	30.57	76.8	52.10	536.8	0.09706	51.93	22.01	10.81
2-21-61 1405	0.9410	21.56	30.48	76.3	52.04	536.3	0.09704	51.91	21.99	10.80
2-23-61 0920	2.7431	21.69	30.00	72.8	51.69	532.8	0.09702	51.90	21.98	10.79

[1] See B. Hoffman, et al., "Mechanical Computer Components - Task 2 - Sealing of Fire Control Instruments," pgs 15-16, Interim Test Report No. 1-FY-60, Sep 1959, for derivation.

Where:

$$P_2 = \frac{p_1 + B_1}{T_1 + 460} \times 534, \ \text{"Hg}$$

$$p_2 = (P_2 - 29.92), \ \text{"Hg}$$

$$V = 21.21 \ \text{in.}^3$$

$$B_s = 14.7 \ \text{psi}$$

$$K = \frac{B_s}{V}, \ \text{psi/in.}^3$$

$$a = \frac{2.3\left[\text{Log } p^*_{2_1} - \text{Log } p^*_{2_2}\right] \times 365}{\Delta\theta \cdot K}, \ \text{in.}^3\text{/year-psi}$$

$$a = \frac{(2.3)\left[\text{Log } 10.81 - \text{Log } 10.79\right] \times 365}{\left(2.7431\right)\left(\frac{14.7}{21.21}\right)}$$

$$= \frac{(2.3)\ (0.00081)(21.21)(365)}{(2.7431)(14.7)}$$

$$a = \underline{0.357 \ \text{in.}^3\text{/year-psi}}$$

Shrunk and Soldered Joint Construction (see figure 2)

Date Hour	Time θ-Days	p_1 "Hg	B_1 "Hg	T_1 °F	$p_1 + B_1$ "Hg	$T_1 + 460$ °R	$\frac{p_1 + B_1}{T_1 + 460}$	P_2 "Hg	p_2 "Hg	p_2^* psi
1-4-61 1430	0	21.16	30.16	69.6	51.32	529.6	0.09690	51.84	21.92	10.76
1-6-61 1000	1.8125	21.13	30.19	69.9	51.32	529.9	0.09685	51.81	21.89	10.75
1-10-61 1600	6.0625	20.65	30.55	69.0	51.20	529.0	0.09679	51.78	21.86	10.73
1-20-61 1615	16.0729	21.44	29.83	70.0	51.27	530.0	0.09674	51.76	21.84	10.72
1-24-61 1040	19.84	21.34	29.99	70.5	51.33	530.5	0.09676	51.77	21.85	10.72
1-31-61 1025	26.83	20.58	30.37	67.3	50.95	527.3	0.09662	51.69	21.77	10.69

Where:

$$P_2 = \frac{p_1 + B_1}{T_1 + 460} \times 535, \text{ "Hg}$$

$$p_2 = (P_2 - 29.92), \text{ "Hg}$$

$$V = 47.124 \text{ in.}^3$$

$$Bs = 14.7 \text{ psi}$$

$$K = \frac{Bs}{V}, \text{ psi/in.}^3$$

$$a = \frac{2.3\left[\text{Log } p^*_{2_1} - \text{Log } p^*_{2_2}\right] 365}{\Delta\theta \cdot K}\text{, in.}^3\text{/year-psi}$$

$$a = \frac{(2.3)\left[\text{Log } 10.76 - \text{Log } 10.69\right](365)}{(26.83)\left(\frac{14.7}{47.124}\right)}$$

$$a = \frac{(2.3)(0.00283)(47.124)(365)}{(26.83)(14.7)}$$

$$a = \underline{0.283 \text{ in.}^3\text{/year-psi}}$$

"O"-ring and Mercury Seal Joint Construction (see figures 3 and 4)

Date Hour	Time θ-Days	P_1 "Hg	B_1 "Hg	T_1 °F	$P_1 + B_1$ "Hg	$T_1 + 460$ °R	$\frac{P_1 + B_1}{T_1 + 460}$	P_2 "Hg	p_2 "Hg	p^*_2 psi
1-26-61 1540	0	21.32	30.25	71.6	51.57	531.6	0.09701	51.90	21.98	10.79
1-27-61 1600	1.0139	21.30	30.04	69.8	51.34	529.8	0.09690	51.84	21.92	10.76
1-30-61 1555	4.0104	20.95	30.42	70.7	51.37	530.7	0.09680	51.79	21.87	10.74
1-31-61 0840	4.708	20.80	30.39	69.8	51.19	529.8	0.09662	51.69	21.77	10.69

Where:

$$P_2 = \frac{P_1 + B_1}{T_1 + 460} \times 535, \text{ "Hg}$$

$$p_2 = (P_2 - 29.92) \text{ "Hg}$$

$$V = 21.21 \text{ in.}^3$$

$$B_s = 14.7 \text{ psi}$$

$$K = \frac{B_s}{V}, \text{ psi/in.}^3$$

$$a = \frac{2.3\left[\text{Log } p^*_{2_1} - \text{Log } p^*_{2_2}\right] \times 365}{\Delta\theta \cdot K}, \text{ in.}^3\text{/year-psi}$$

$$a = \frac{(2.3)\left[\text{Log } 10.79 - \text{Log } 10.69\right](365)}{(4.708)\left(\frac{14.7}{21.21}\right)}$$

$$= \frac{(2.3)(0.00404)(21.21)(365)}{(4.708)(14.7)}$$

$$a = \underline{1.04 \text{ in.}^3\text{/year-psi}}$$

<u>Metal-To-Metal Joint Secured By Heavy Strap Force Through Needle Bearings (see figure 5)</u>

Date Hour	Time θ-Days	P_1 "Hg	B_1 "Hg	T_1 °F	$P_1 + B_1$ "Hg	$T_1 + 460$ °R	$\frac{P_1 + B_1}{T_1 + 460}$	P_2 "Hg	P_2 "Hg	P_2^* psi
3-29-61 1015	0	23.10	29.96	78.0	53.06	538.0	0.09862	52.76	22.84	11.21
3-29-61 1335	0.139	23.15	29.92	78.3	53.07	538.3	0.09858	52.74	22.82	11.20
3-30-61 1600	1.240	22.90	30.02	77.3	52.92	537.3	0.09849	52.69	22.77	11.18
4-6-61 1630	8.260	22.89	29.88	77.0	52.77	537.0	0.09827	52.57	22.65	11.12

Where:

$$P_2 = \frac{p_1 + B_1}{T_1 + 460} \times 535, \text{ "Hg}$$

$$p_2 = (P_2 - 29.92), \text{ "Hg}$$

$$V = 47.124, \text{ in.}^3$$

$$B_s = 14.7, \text{ psi}$$

$$K = \frac{B_s}{V}, \text{ psi/in.}^3$$

$$a = \frac{2.3\left[\text{Log } p^*_{2_1} - \text{Log } p^*_{2_2}\right] \times 365}{\Delta\theta \cdot K}, \text{ in.}^3\text{/year-psi}$$

$$a = \frac{(2.3)\left[\text{Log } 11.21 - \text{Log } 11.12\right](365)}{(8.260)\left(\frac{14.7}{47.124}\right)}$$

$$a = \frac{(2.3)(0.00351)(47.124)(365)}{(8.260)(14.7)}$$

$$a = \underline{1.14 \text{ in.}^3\text{/year-psi}}$$

APPENDIX C

DISCUSSION OF NONTESTED PARAMETERS OF "O"-RING ROTARY SEALS WHICH IT IS BELIEVED WILL AFFECT FLOW PATH GEOMETRIES AND THUS THE RATE OF INFLOW OF MOISTURE THROUGH THE ROTARY SEAL

There are various parameters that affect the geometries of the leakage flow paths through a rotary seal which will vary due to normal manufacturing tolerances. It is suspected that some or all may sufficiently alter the flow paths to cause differences in moisture flow rates past otherwise identical rotary seals. A list of these parameters follows:

1. Surface condition (finishes) of both "O"-ring and the mating shaft and housing groove.

2. Physical dimensions of shaft (O.D. and ovality), of "O"-ring (I.D., width of cross section) and of housing groove (width and depth) as well as concentricity of shaft and housing groove.

3. "O"-ring lubrication as affects friction characteristics of relative moving parts; hence, wear and contact roughness.

4. Homogenity of "O"-ring composition and hardness which affects wear quality and diffusion rate through the "O"-ring material itself.

APPENDIX D

DISCUSSION OF VARIOUS CONSIDERATIONS IN FINAL DESIGN OF LEAKPROOF TEST CHAMBERS

As discussed in Appendix C there are various parameters that affect the geometries of the leakage flow paths through a rotary seal which will vary due to normal manufacturing tolerances. Because changes in leakage flow path geometry will have a very strong affect upon the magnitude and characteristics of the moisture flow rate, it is essential that the normal manufacturing tolerances be tightened to minimize these random fluctuations. Consequently, in the test chamber design the tolerance tightening process consisted of the following:

1. As concerns "O"-rings, 1000 of a given size were procured from the same batch lot (hence, same composition and hardness) and each was examined for width of cross section, I. D. and flash conditions as well as scratches or other imperfections. The "O"-rings selected for inclusion in the test chambers have the I. D. and width of cross section held within 0. 001", have excellent flash conditions, have no imperfections as concerns scratches, mars, etc., and are identical in composition and hardness.

2. The shafts are fabricated with identical surface finishes (RMS 16), have O. D.'s held within 0. 0001", use class 5 bearings and are concentric with bearing housings and "O"-ring housing grooves within very close tolerances.

3. In addition, the "O"-ring housing groove width and depth are held within 0. 0002".

Because of cost considerations, it was desirous to minimize the statistical sample size of "O"-rings per test chamber that must be employed. The following considerations governed the choice of 10 "O"-rings per chamber:

1. The larger the number the more confidence that the statistical average represents the true condition to be expected.

2. The larger the number, the greater the inflow of moisture and outflow of nitrogen gas through the seals. Therefore, the less difficult it becomes to meet the requirement of fabricating a test chamber with required low leakage characteristics.

3. The larger the number, the larger the volume of the test chamber that can be used and still obtain a large enough change in percent relative humidity to be accurately sensed in a reasonably short test period. A large volume of test chamber is desired to lessen the chance of sensor elements loading down the system.

4. The more closely the random variables of the "O"-ring and its mating shaft and housing groove (as introduced by normal manufacturing tolerances) are controlled, the smaller the standard deviation and hence, the smaller the sample size required for the same confidence level of test data.

As concerns size of test chamber, it would be desirous that the volume be as small as possible to maximize moisture change per unit time (for the given number of "O"-ring seals chosen per test chamber) and thus increase system resolution. However, the chamber must be large enough that

1. Sensors do not load down the system.

2. Pressures remain essentially constant during the test period (as constant pressure test chambers are desired).

The actual chamber size was determined quantitatively by the constant pressure consideration. Based on a maximum estimated total gas leakage rate of 2.0 in.^{3}/year-psi for each "O"-ring seal and an allowance for a 10 percent drop in gage pressure over a two month test period, it was calculated that a minimum of approximately 500 in.^{3} chamber volume would be required. The chambers were designed to have a volume slightly in excess of 500 in.^{3} to be on the conservative side.

REFERENCES

1. Memorandum-To-Project File, "Determination of Laws Governing Inflow of Moisture Through a Rotary Seal," dated 14 March 1961.

2. Memorandum-To-Project File, dated 10 May 1961.

3. Memorandum-To-Project File, dated 21 July 1961.

4. Memorandum-To-Project File, dated 17 August 1961.

DISTRIBUTION

25 -	Commanding Officer Frankford Arsenal Philadelphia 37, Pa. Attn: Thru: Chief, 1500	
	Chief, 1510	(1)
	Chief, 1520	(1)
	Chief, 1530	(1)
	Chief, 1540	(1)
	Thru: Chief, 1100	
	Chief, 1110	(1)
	Chief, 1120	(1)
	1110, C. Dobson	(1)
	1120, B. Hoffman	(5)
	1000, Dr. Chwalow	(1)
	Thru: Senior Scientist, 0100	
	Library, 0270	(1)
	Chief, 1040	(1)
	1214	(10)
1 -	Headquarters U.S. Army Materiel Command Washington 25, D. C. Attn: AMCRD-DE-MO	
10 -	Armed Services Technical Inforamtion Agency Arlington Hall Station Arlington 12, Va. Attn: TIPDR	

AD- ACCESSION NO.
M63-1-2

Frankford Arsenal, Philadelphia 37, Pa.
DETERMINATION OF THE MECHANISMS GOVERNING THE INFLOW OF MOISTURE PAST A ROTARY SEAL - STATUS REPORT by Bernard Hoffman

Memorandum Report M63-1-2, January 1963, 45 pp incl illustrations and appendices (OMS 5522.11.441, DA Proj 513-01-008) UNCLASSIFIED REPORT

This report describes the design of an experiment to verify the mechanisms governing the transport of moisture past a rotary seal. The mechanisms were determined after extensive search of the technical literature; consultations with persons knowledgeable in the field of water vapor and related phenomena; and they are presented in Memorandum Report No. M63-1-1 dated January 1963.

Nonexistence of suitable testing facilities required the design and development of special equipments necessary

(Cont'd)

UNCLASSIFIED

1. Artillery Fire Control Applied Research
2. Rotary Seals ("O"-rings)

I. Hoffman, Bernard
II. OMS 5522.11.441

DISTRIBUTION LIMITATIONS:
Qualified requesters may obtain copies of this report from ASTIA.

UNCLASSIFIED

AD- ACCESSION NO.
M63-1-2

Frankford Arsenal, Philadelphia 37, Pa.
DETERMINATION OF THE MECHANISMS GOVERNING THE INFLOW OF MOISTURE PAST A ROTARY SEAL - STATUS REPORT by Bernard Hoffman

Memorandum Report M63-1-2, January 1963, 45 pp incl illustrations and appendices (OMS 5522.11.441, DA Proj 513-01-008) UNCLASSIFIED REPORT

This report describes the design of an experiment to verify the mechanisms governing the transport of moisture past a rotary seal. The mechanisms were determined after extensive search of the technical literature; consultations with persons knowledgeable in the field of water vapor and related phenomena; and they are presented in Memorandum Report No. M63-1-1 dated January 1963.

Nonexistence of suitable testing facilities required the design and development of special equipments necessary

(Cont'd)

UNCLASSIFIED

1. Artillery Fire Control Applied Research
2. Rotary Seals ("O"-rings)

I. Hoffman, Bernard
II. OMS 5522.11.441

DISTRIBUTION LIMITATIONS:
Qualified requesters may obtain copies of this report from ASTIA.

UNCLASSIFIED

AD- ACCESSION NO.
M63-1-2

Frankford Arsenal, Philadelphia 37, Pa.
DETERMINATION OF THE MECHANISMS GOVERNING THE INFLOW OF MOISTURE PAST A ROTARY SEAL - STATUS REPORT by Bernard Hoffman

Memorandum Report M63-1-2, January 1963, 45 pp incl illustrations and appendices (OMS 5522.11.441, DA Proj 513-01-008) UNCLASSIFIED REPORT

This report describes the design of an experiment to verify the mechanisms governing the transport of moisture past a rotary seal. The mechanisms were determined after extensive search of the technical literature; consultations with persons knowledgeable in the field of water vapor and related phenomena; and they are presented in Memorandum Report No. M63-1-1 dated January 1963.

Nonexistence of suitable testing facilities required the design and development of special equipments necessary

(Cont'd)

UNCLASSIFIED

1. Artillery Fire Control Applied Research
2. Rotary Seals ("O"-rings)

I. Hoffman, Bernard
II. OMS 5522.11.441

DISTRIBUTION LIMITATIONS:
Qualified requesters may obtain copies of this report from ASTIA.

UNCLASSIFIED

AD- ACCESSION NO.
M63-1-2

Frankford Arsenal, Philadelphia 37, Pa.
DETERMINATION OF THE MECHANISMS GOVERNING THE INFLOW OF MOISTURE PAST A ROTARY SEAL - STATUS REPORT by Bernard Hoffman

Memorandum Report M63-1-2, January 1963, 45 pp incl illustrations and appendices (OMS 5522.11.441, DA Proj 513-01-008) UNCLASSIFIED REPORT

This report describes the design of an experiment to verify the mechanisms governing the transport of moisture past a rotary seal. The mechanisms were determined after extensive search of the technical literature; consultations with persons knowledgeable in the field of water vapor and related phenomena; and they are presented in Memorandum Report No. M63-1-1 dated January 1963.

Nonexistence of suitable testing facilities required the design and development of special equipments necessary

(Cont'd)

UNCLASSIFIED

1. Artillery Fire Control Applied Research
2. Rotary Seals ("O"-rings)

I. Hoffman, Bernard
II. OMS 5522.11.441

DISTRIBUTION LIMITATIONS:
Qualified requesters may obtain copies of this report from ASTIA.

UNCLASSIFIED

AD- ACCESSION NO.
M63-1-2 (Cont'd)

to conduct the experiment. These equipments included special moisture sensors with associated indicating device and suitable sensor calibration means; leakproof chambers for simulating fire control instruments; means for simulating various modes of rotation; and a constant temperature environmental chamber. The testing facilities and their state of completion at the end of FY-1962 are discussed herein. The design, development, procurement and/or fabrication constitute the major effort during FY-1962.

Recommendations to continue the program are made; cost and time estimates for completion of testing facilities and carrying out of experiment are presented.

UNCLASSIFIED

UNCLASSIFIED

AD- ACCESSION NO.
M63-1-2 (Cont'd)

to conduct the experiment. These equipments included special moisture sensors with associated indicating device and suitable sensor calibration means; leakproof chambers for simulating fire control instruments; means for simulating various modes of rotation; and a constant temperature environmental chamber. The testing facilities and their state of completion at the end of FY-1962 are discussed herein. The design, development, procurement and/or fabrication constitute the major effort during FY-1962.

Recommendations to continue the program are made; cost and time estimates for completion of testing facilities and carrying out of experiment are presented.

UNCLASSIFIED

UNCLASSIFIED

AD- ACCESSION NO.
M63-1-2 (Cont'd)

to conduct the experiment. These equipments included special moisture sensors with associated indicating device and suitable sensor calibration means; leakproof chambers for simulating fire control instruments; means for simulating various modes of rotation; and a constant temperature environmental chamber. The testing facilities and their state of completion at the end of FY-1962 are discussed herein. The design, development, procurement and/or fabrication constitute the major effort during FY-1962.

Recommendations to continue the program are made; cost and time estimates for completion of testing facilities and carrying out of experiment are presented.

UNCLASSIFIED

UNCLASSIFIED

AD- ACCESSION NO.
M63-1-2 (Cont'd)

to conduct the experiment. These equipments included special moisture sensors with associated indicating device and suitable sensor calibration means; leakproof chambers for simulating fire control instruments; means for simulating various modes of rotation; and a constant temperature environmental chamber. The testing facilities and their state of completion at the end of FY-1962 are discussed herein. The design, development, procurement and/or fabrication constitute the major effort during FY-1962.

Recommendations to continue the program are made; cost and time estimates for completion of testing facilities and carrying out of experiment are presented.

UNCLASSIFIED

UNCLASSIFIED